

Polyethylene glycol induced drought tolerance traits and their association in seedlings of wheat genotypes

Kyi Pyar Aye¹, Soe Win^{2*}, Nyo Mar Htwe³ and Yinn Mar Soe⁴

Yezin Agricultural University, Myanmar

Corresponding Author's Email: soewin@yau.edu.mm

Received: May 2025; Revised Accepted: August 2025

ABSTRACT

Seedling growth is hindered by drought stress differently across various genotypes; some genotypes being susceptible, are affected more while others exhibit tolerance to drought. Thus, the current study was undertaken to: (1) identify the drought tolerant wheat genotypes, and (2) examine correlation among drought related traits. The performance of 23 wheat genotypes including 21 wheat genotypes and two check varieties were tested under control (distilled water) and -0.407 Mpa (Polyethylene Glycol, PEG-6000) induced osmotic stress during germination and early seedling growth stages. The experiment was arranged in a three-time replicated randomized complete block design at the Laboratory of Department of Plant Breeding, Physiology and Ecology, Yezin Agricultural University. The combined analysis of variance indicated highly significant differences among genotypes, treatments and genotypes $\times$ treatments interaction for all seedling traits except mean germination time. Out of the 21 genotypes evaluated, 19 showed potential drought tolerance under PEG solution due to possessing desirable traits, such as seedling vigor index II, root length and root dry weight. Correlation coefficients among seedling traits were significant and positive for all studied traits except mean germination time which had no significant correlation with any of other traits. The results indicated that the increase in one trait may cause a simultaneous increase in other traits; hence selection for any of these seedling attributes will lead to develop drought tolerant wheat genotypes. The principal components with eigen values greater than 1 are deemed important and in this study, it had the total variation of 83.87 %. Therefore, these seedling traits in wheat genotypes could be used good indicator of drought tolerance in the breeding program.

Keywords: Wheat genotypes, polyethylene glycol, osmotic stress, seedling

INTRODUCTION

Wheat (*Triticumaestivum* L.) is the most extensively cultivated cereal crop as well as provides a major proportion of supplied dietary calories, minerals, and around 20% of the required pro-

tein alongside the first important and strategic crop for the world's population. This crop is the staple food for over 35% of world population, and thus, ensures food security of the world (Kushwaha *et al.*, 2018; Dass *et al.*, 2023). However, global wheat production has been lowered by 2.7 million tons (mt) down to 781.2 mt in 2022 because of prolonged dry weather conditions impairing yields (FAO, 2022). In Myanmar, wheat was cultivated in 0.054 million hectare (mha) with a production of 0.11 mt at an average yield of 1.89 tha^{-1} . Seventy-three per cent of the Dry Zone's growing areas were in the Sagaing Region, 23%

¹Ph.D.Scholar, ²Professor and Head, Department of Plant Breeding, Physiology and Ecology, Yezin Agricultural University, Myanmar

³Professor and Head, Advanced Center for Agricultural Research and Education, Yezin Agricultural University, Myanmar

⁴Associate Professor, Department of Soil and Water Science, Yezin Agricultural University, Myanmar

in Shan State and 4% in the Mandalay Region (MOALI, 2022). National consumption yearly exceeds 0.5 mt, only 0.18 mt of which was produced in Myanmar (the rest was imported from Australia). The influence of unfavorable weather conditions plays a vital role in wheat production, since wheat cultivation mainly depends upon the residual moisture. Various screening methods were evaluated in stress tolerance varieties, such as hydro-priming, halo-priming, chemical priming, and osmo-priming, which enhanced seed germination under osmotic stress and the drought tolerance in seedlings (Jisha *et al.*, 2012). The major objectives of many breeding programs have been to develop stress-tolerant varieties, which are crucial in the face of global warming. This warming trend alters the amount and distribution of precipitation, potentially leading to more frequent and severe droughts which is regarded as a severe constraint on agricultural crop production throughout the world (Nezhadahmadi, 2013). However, the efforts have been limited due to inadequate screening techniques and the absence of genotypes that show apparent differences in response to well-defined abiotic stresses. It is possible to measure drought-related characteristics in early generations under controlled laboratory conditions or during the off-season, which makes this a promising as well as affordable approach. One of the most important growth stages is the seedling emergence, that can be impacted by a water deficit. The availability of soil moisture can have a significant impact on germination and subsequent emergence. Insufficient soil moisture not only reduces overall germination but also delays the emergence of seeds. Ashraf and Foolad (2005) claimed that low moisture content reduces the percentage of germination and the growth of seedlings. Seed germination and seedling growth properties are incalculably vital factors for yield determination (Rauf *et al.*, 2007). However, seed germination and early seedling growth are certainly the most critical stages, strongly impaired by water stress (Swain *et al.*, 2014). Thus, it appears that the most important and effective strategy is to select genotypes resistant to drought earlier in the growing season (Xie *et al.*, 2013). There was an enhancement in wheat yield as the best-performing varieties under water stress are

selected. Tolerance to drought has been an important goal in crop improvement programs (Abro *et al.*, 2020; Ahmad *et al.*, 2013).

It has been recognized that the seedling development stage under laboratory situations is an appropriate growth stage for showing wheat's ability to respond to osmotic stress conditions. When seeds are immersed in artificial substances, such as polyethylene glycol (PEG), sorbitol, or mannitol solution, they are referred to as osmo-priming (also known as osmo-conditioning). This allows the seeds to absorb water and begin the primary metabolic activities of germination, leading to radical emergence (Ashraf and Foolad, 2005). Polyethylene glycol (PEG) 6000 was used in the experiment. It is a non-ionic water polymer that is known for its unexpected ability to quickly absorb plant tissue and induce water stress (Bagher *et al.*, 2012). According to earlier research by Tang *et al.* (2019), one effective method of screening genotypes tolerant to drought is concluded in-vitro screening utilizing PEG. More prominently, Shereen *et al.* (2019) found that the methods for screening wheat genotypes tolerant to drought using PEG 6000 are economical and effective. Many researchers utilize PEG6000 to examine the response of various wheat genotypes to drought stress at different levels (osmotic pressure) (Abro *et al.*, 2020). The objective of the current study was intended to identify wheat genotypes for drought tolerance at early seedling growth stages by using PEG-6000 and also examine the correlation between drought related seedling traits.

MATERIALS AND METHODS

This experiment was carried out during 2023 (May to July), at the laboratory of Department of Plant Breeding, Physiology and Ecology (ELB-2), Yezin Agricultural University (YAU), Myanmar. The tested varieties consisted of twenty-one wheat genotypes and two check varieties (Appendix 1). Seeds were obtained (introduced from the International Maize and Wheat Improvement Center (CIMMYT) and Regional Research Center (Zaloke)) under the Department of Agricultural Research (DAR).

The experiment was carried out following a randomized complete block design with three

replications under control and PEG-6000 at concentration: 0, and 18% (-0.407 MPa). PEG was used because it has a high molecular weight, it cannot pass through the cell wall and therefore, it is used to regulate water potential in germination tests. PEG 6000 was used to evaluate tolerance to drought at germination stage and to create different levels of water potential. Drought tolerance was evaluated in two stages: seed germination and seedling growth. The study was performed in petri plates having filter paper. The seeds were

selected for size homogeneity; surface sterilized for 5 min in 1 % (v/v) sodium hypochlorite and then rinsed three times with distilled water. Wheat seeds were subjected to two levels PEG-6000 stress (0 and 180 g/L), (0.00 and -0.407 Mpa), respectively, was prepared according to Michel and Kaufmann (1973). Three replicates of 20 pre-sterilized seeds were germinated between 2 sheets of Whatman No. 2 filter papers in petri dishes (90-mm in diameter) with 10 ml of each test solution and filter papers were replaced in every other day

Appendix 1. List of wheat genotypes used for control and PEG-6000 solutions study

No.	Genotypes	Pedigree	Source
1	26 th SAWYT-30	BORL14*2//KFA/2*KACHU CMSS12B00633T-099TOPY-099M-0SY-3M-0WGY	CIMMYT
2	26 th SAWYT-48	BABAX/LR42//BABAX*2/3/KUKUNA/4/CROSBILL#1/5/BECARD*2/... CMSS12B00995T-099TOPY-099M-0SY-19M-0WGY	CIMMYT
3	20 th HTWYT-6	KAKURU/BORL14CMSS14Y00217S-099Y-099M-099NJ-099NJ-20Y-0WGY	CIMMYT
4	20 th HTWYT-7	KAKURU//SUP152/BAJ #1CMSS14Y00218S-099Y-099M-099NJ-099NJ-14Y-0WGY	CIMMYT
5	20 th HTWYT-8	KACHU*2/SUP152/3/WBLL*2/BRAMBLING*2//BAVISCMS14Y00360S-099Y-099M-099NJ-099NJ-24Y-0WGY	CIMMYT
6	20 th HTWYT-9	FRANCOLIN#1/NELOKI/3/PRL/2*PASTOR//KACHUCMSS14Y00582S-099Y-099M-099NJ-099NJ-20Y-0WGY	CIMMYT
7	20 th HTWYT-12	HARTOG`SUMA13(LINE B)/2*NAVJ07/4/MUTUS//KIRITATI/... CMSS14Y01116S-099Y-0FUS-099Y-149B-0WGY-0WGY	CIMMYT
8	20 th HTWYT-15	KACHU/DANPHE*2//MUTUS*2/HARIL#1CMSS14Y01489T-099TOPM-099Y-099M-099NJ-099NJ-39Y-0WGY	CIMMYT
9	20 th HTWYT-25	SUP152/KENYA SUNBIRD/3/KACHU//KIRITATI/2*TRCHCMSS14B00275S-099M-099NJ-099NJ-9Y-0WGY	CIMMYT
10	20 th HTWYT-33	WBLL1*2/KIRITATI//FRNCLN/3/BECARD/4/2*KACHU/DANPHECMSS14B01413T-099TOPY-099M-099NJ-099NJ-8Y-0WGY	CIMMYT
11	20 th HTWYT-34	WBLL1*2/KIRITATI//FRNCLN/3/BECARD/4/2*KACHU/DANPHECMSS14B01413T-099TOPY-099M-099NJ-099NJ-13Y-0WGY	CIMMYT
12	20 th HTWYT-45	WBLL1*2/4/YACO/PBW65/3/KAUZ*2/MNV//KAUZ/5/KACHU#1*2CMSS14B01702T-099TOPY-099M-099NJ-099NJ-23Y-0WGY	CIMMYT
13	20 th HTWYT-46	ORION/5/2*FRNCLN/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//CMSS14B01780T-099TOPY-099M-099NJ-099NJ-5Y-0WGY	CIMMYT
14	20 th HTWYT-47	ESTOC/7/2*KISKADEE # 1/5/KAUZ *2/MNV//KAUZ/3/MILAN/4/... CMSS14B01796T-099TOPY-099M-099NJ-099NJ-13Y-0WGY	CIMMYT
15	20 th HTWYT-49	NADI # 2/MUCUYCMSS15B00235S-099M-0SY-7M-0WGY	CIMMYT
16	29 th SAWYT-7	NGL/4/PFAU/MILAN/3/BABAX/LR42//BABAX/5/WBLL1*2/...CMSS14Y00713S-099Y-099M-099NJ-099NJ-1Y-0WGY	CIMMYT
17	29 th SAWYT-9	KACHU/DANPHE*2//KAKURUCMSS14Y01492T-099TOMP-099Y-099M-099NJ-099NJ-28Y-0WGY	CIMMYT
18	29 th SAWYT-17	WBLL1*2/BRAMBLING*2//BAVIS*2/3/KACHU#1/KIRITATI//KACHUCMSS14Y01752T-099TOMP-099Y-099M-099NJ-099NJ-7Y-0WGY	CIMMYT
19	29 th SAWYT-37	BAJ#1/KISKADEE#1/3/WBLL1*2/BRAMBLING*2//BAVIS/4/...CMSS14B01442T-099TOPY-099M-099NJ-099NJ-20Y-0WGY	CIMMYT
20	29 th SAWYT-39	ROLF07*2/SHORTENED SR26 TRANSLOCATION/3/2*WBLL1*2/CMSS14B01476T-099TOPY-099M-099NJ-099NJ-11Y-0WGY	CIMMYT
21	29 th SAWYT-43	SWSR22T.B.//TACUPETO F2001*2/BRAMBLING/3/ CMSS15Y00037T-099B-099Y-099M-099Y-16M-0WGY	CIMMYT
22	Yezin-11	12 th SAWYT-44	DAR
23	Yezin-12	SUP-152	DAR

to prevent PEG accumulation at 25 °C in the dark (Rehman *et al.*, 1997). Number of seeds germinated was manually counted on each day up to 7 days and the seed germination characters were considered based on the emergence of the radicle and plumule (2 mm). After ten days, seedling vigor index was measured by the protocol of International Seed Testing Association (ISTA 1999). By the end of the 10th day, root length (cm), shoot length (cm), shoot dry weight (mg) and root dry weight (mg) were measured. Germination percentage was calculated by using the following formula according to Španie *et al.* (2017).

$$\text{Germination percentage (G\%)} = \frac{\text{Germinated seeds}}{\text{Total seeds}} \times 100$$

Mean germination time was calculated by using the following formula as suggested by Dezfuli, *et al.* (2008). Mean germination rate (MGR) was considered as the reciprocal of the mean germination time (Ranal and Santana, 2006), seedling vigor index I and seedling vigor index II (Chakraborty and Bose, 2023).

$$\text{Mean germination time (MGT)} = \frac{\sum n_i t_i}{\sum n_i}$$

Seedling vigor index I = Germination per cent × (shoot length + root length)

Seedling vigor index II = Germination per cent × seedling dry weight

All the collected data from this experiment was analyzed by using the computer based Statistical Tool for Agricultural Research (STAR) software 2.0.1.

RESULTS AND DISCUSSION

Combined analysis of variance

The combined analysis of variance revealed that the genotypes showed a highly significant effect on all traits which have valuable genetic variability for plant breeding program. Polyethylene glycol 6000 (PEG-6000) used in this research has an osmotic agent. PEG-6000 was used to evaluate tolerance to drought at germination and seedling stages to create different levels of water potential. PEG-6000 is used by many researchers to study the ability of different wheat genotypes to tolerate drought stress. The cooperative effects of genotypes and PEG-6000 induced drought stress in line with treatments significantly changed in all observed traits, except mean germination time, which was indicated non-significant (Table 1). The results of this study displayed highly significant differences between genotypes and treatment showing a key prerequisite for genetic improvement in plant breeding and played a pivotal role in experimental material usage in breeding programs. Similar results were demonstrated by many researchers (Bayoumi *et al.* (2008), Rauf *et al.* (2007) and Dhanda *et al.* (2004), they found that PEG treatment had a significant effect of on wheat seedling traits and also varietal and differential response of varieties to PEG treatment.

Germination and seedling traits of wheat genotypes

Germination and seedling traits of wheat

Table 1. Combined analysis of variances for observed seedling traits in tested wheat genotypes under control and osmotic potential

Traits	Rep within genotypes	Genotypes	Treatment	Geno × treatment	Pooled error	CV%
	46	22	1	22	46	
Germination percentage (%)	0.28	7.20**	78.05**	7.20**	0.25	0.53
Germination rate	0.43	84.26**	685.15**	53.27**	0.43	5.09
Mean germination time	0.02	0.05**	0.02ns	0.02ns	0.02	10.83
Root length (cm)	0.19	8.67**	150.97**	6.40**	0.13	3.36
Shoot length (cm)	0.43	6.32**	243.84**	2.03**	0.28	4.40
Shoot dry weight (mg)	0.18	6.70**	27.31**	4.09 **	0.22	4.37
Root dry weight (mg)	0.05	3.72**	464.61**	2.23**	0.04	3.28
Seedling vigour index I	10021.58	223395.17**	274339.084**	148655.11**	4378.11	2.93
Seedling vigour index II	3211.58	162364.62**	2164753.37**	93010.11**	3261.24	3.41

ns = non-significant, * = significant at 0.05 probability level and ** = significant at 0.01 probability level

genotypes were significantly responded by the influence of drought stress (Table 2). In the present study, the maximum seed germination per cent (GP) (100%) was recorded in 26th SAWYT-30, 20th HTWYT-7, 20th HTWYT-8, 20th HTWYT-12, 20th HTWYT-15, 29th SAWYT-7, 29th SAWYT-9, 29th SAWYT-17, 29th SAWYT-37, 29th SAWYT-39, 29th SAWYT-43, Yezin-11 and Yezin-12, and minimum in 20th HTWYT-49 (94%) under stress condition (Table 2). PEG 6000 induced osmotic stress and delayed the initiation of germination that led to reduction in germination percentage. These findings were in worthy agreement with those obtained by Dhanda *et al.* (2004), Jajarmi (2009), Khakwani *et al.* (2011) and Raza *et al.* (2012). Among the tested genotypes, the genotype 26th SAWYT- 30 (20.00) gave the highest germination rate (GR) and the genotype 20th HTWYT-47 had the lowest germination rate (5.28). The mean germination time (MGT) also reduced with the increase level of drought stress. However, the MGT of 20th HTWYT-46 (1.42), 20th HTWYT-12 and 20th HTWYT-45 (1.22) was found to be higher in PEG-

6000 solution. Genotype namely 26th SAWYT- 30 (1.00) recorded the lowest MGT in the study experiment.

Based on the study, it was observed that the root length of wheat genotypes enlarged significantly as the levels of Polyethylene Glycol (PEG) increased. Genotypes *viz.*, 20th HTWYT-15 (14.07 cm), 29th SAWYT-43 (13.90 cm) and 29th SAWYT-39 (13.49 cm) and 29th SAWYT-7 (13.46 cm) showed the maximum root length in control and PEG 6000 conditions whereas the lowest root length was observed in genotype, 20th HTWYT-33 (8.73 cm) (Table 2 and Fig.1). Similar results have been reported by Khakwani *et al.* (2011) who stated that PEG increased the root length. Furthermore, the effects of drought treatments on shoot length were varied among the genotypes, the maximum shoot length was in 20th HTWYT-34 (12.70 cm) followed by 29th HTWYT-9 (12.11 cm) and 20th HTWYT-15 (11.94 cm) at the PEG treatment. The minimum shoot length was revealed in genotype 20th HTWYT-6 (9.05 cm). The genotype 20th HTWYT-25 (12.29 mg) had the longest shoot dry weight

Table 2. Mean value of wheat genotypes seedling traits by using PEG 6000 solution

	Genotypes	GP	GR	MGT	RL	SL	SDW	RDW	SVI I	SVI II
1	26 th SAWYT-30	100.00	20.00	1.00	10.71	9.36	8.95	9.06	2007.73	1801.13
2	26 th SAWYT-48	96.61	15.49	1.09	9.92	9.78	9.13	6.91	1903.36	1549.16
3	20 th HTWYT-6	98.35	14.75	1.08	12.71	9.05	10.73	9.14	2140.51	1954.07
4	20 th HTWYT-7	100.00	6.37	1.17	9.59	9.89	9.38	8.17	1948.50	1755.56
5	20 th HTWYT-8	100.00	11.31	1.08	11.80	10.11	10.23	7.97	2191.17	1819.31
6	20 th HTWYT-9	96.65	11.49	1.14	12.43	11.03	10.25	8.70	2268.70	1831.60
7	20 th HTWYT-12	100.00	5.51	1.22	12.90	11.31	10.93	9.38	2420.91	2031.58
8	20 th HTWYT-15	100.00	8.49	1.12	14.07	11.94	12.13	8.69	2600.40	2081.69
9	20 th HTWYT-25	98.33	15.95	1.04	12.54	10.11	12.29	8.99	2227.50	2091.91
10	20 th HTWYT-33	96.69	10.59	1.14	8.73	10.53	9.22	7.53	1862.95	1619.39
11	20 th HTWYT-34	98.60	5.91	1.20	11.78	12.70	10.79	7.55	2414.02	1808.58
12	20 th HTWYT-45	93.92	10.38	1.22	11.15	11.29	10.38	8.68	2107.57	1790.85
13	20 th HTWYT-46	98.74	5.28	1.42	9.83	11.13	8.78	5.57	2069.00	1416.40
14	20 th HTWYT-47	93.80	11.72	1.11	10.96	10.56	11.78	9.19	2019.85	1967.03
15	20 th HTWYT-49	93.72	6.37	1.14	10.87	10.76	9.54	6.87	2028.10	1538.71
16	29 th SAWYT-7	100.00	13.31	1.03	10.89	9.48	9.59	6.59	2037.09	1617.61
17	29 th SAWYT-9	100.00	13.46	1.08	13.61	12.11	10.18	9.47	2571.73	1964.95
18	29 th SAWYT-17	100.00	13.56	1.03	13.46	10.84	10.09	7.08	2429.87	1717.07
19	29 th SAWYT-37	100.00	6.93	1.20	12.79	11.83	11.14	9.13	2462.25	2026.61
20	29 th SAWYT-39	100.00	11.85	1.13	13.49	10.31	10.28	9.20	2379.06	1947.39
21	29 th SAWYT-43	100.00	9.93	1.15	13.90	10.84	11.06	7.51	2473.96	1856.87
22	Yezin-11	100.00	8.81	1.17	10.47	10.30	9.29	7.70	2077.20	1698.63
23	Yezin-12	100.00	7.06	1.18	11.70	10.88	9.28	6.30	2258.41	1558.60

GP= Germination percentage (%), GR=Germination Rate, MGT= Mean Germination Time, RL= Root Length (cm), SL= Shoot Length (cm), SDW= Shoot Dry Weight (mg), RDW= Root Dry Weight (mg), SVI I =Seedling Vigour Index I, SVI II =Seedling Vigour Index II

and the genotype 20th HTWYT-46 had the lowest shoot dry weight (12.29 mg) in all tested genotypes. PEG reduced shoot growth. Ming *et al.*, (2012), Moucheshi *et al.* (2012) and Saghafikhadem (2012) reported that drought resistance cate-

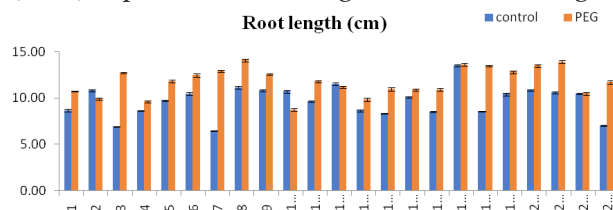


Fig. 1. Mean value of root length (cm) in wheat genotypes tested at control and PEG 6000 solutions

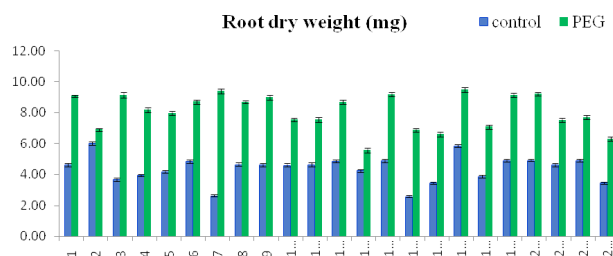


Fig. 2. Mean value of root dry weight (mg) among the tested wheat genotypes by using control and PEG 6000 solutions

gized by a small reduction of shoot growth under drought stressed condition. Moreover, the maximum root dry weight was observed in 29th SAWYT- 9 (9.47 mg) while the minimum root dry weight showed in 29th HTWYT-46 (5.57 mg) (Table 2 and Fig. 2). The genotype 20th HTWYT-15 recorded highest seedling vigor index I, which was 2600.40. While the lowest seedling vigor index I (1862.95) was recorded with genotype 20th HTWYT-33. Moreover, the genotype 20th HTWYT-15 increased seedling vigor index II which had the mean value of 2091.91 whereas the genotype 20th HTWYT-46 decreased seedling vigor index II which had the mean value of 1416.40 as shown in Table 2 and Fig. 3. Similar finding concluded that the development of the root system in response to water deficit was due to the expression of certain genes controlling root formation which was stimulated by drought conditions (Badiow *et al.* 2004).

Traits association of drought tolerant wheat genotypes

A Pearson correlation analysis showed some

Table 3. Correlation coefficients (r) among various seedling traits of wheat genotypes

Traits	GP	GR	MGT	RL	SL	SDW	RDW	SVI.I	SVI.II
Germination percentage (%)	1.000	0.184*	-0.009ns	-0.048ns	0.323**	0.119ns	-0.373**	0.340**	-0.118ns
Germination rate		1.000	-0.424**	-0.235*	0.183*	0.156ns	-0.294**	-0.017ns	-0.139ns
Mean germination time			1.000	-0.100ns	0.082ns	-0.108ns	-0.159ns	-0.017ns	-0.201*
Root length (cm)				1.000	-0.117ns	0.235*	0.701**	0.646**	0.735**
Shoot length (cm)					1.000	0.429**	-0.530**	0.670**	-0.160ns
Shoot dry weight (mg)						1.000	-0.034ns	0.484**	0.575**
Root dry weight (mg)							1.000	0.085ns	0.789**
Seedling vigour Index I								1.000	0.409**
Seedling vigour Index II									1.000

Table 4. Principal component analysis of wheat genotypes seedling traits

Traits	PC1	PC2	PC3	PC4
Germination percentage (%)	-0.059	-0.292	-0.037	0.547
Germination rate	-0.082	-0.231	0.480	0.018
Mean germination time	-0.081	0.042	-0.538	-0.179
Root length (cm)	0.399	0.061	-0.062	0.335
Shoot length (cm)	0.025	-0.457	-0.193	-0.081
Shoot dry weight (mg)	0.247	-0.287	0.082	-0.455
Root dry weight (mg)	0.326	0.333	0.078	0.119
Seedling vigour index I	0.303	-0.322	-0.188	0.269
Seedling vigour index II	0.418	0.079	0.110	-0.092
Eigen values	4.844	3.662	2.177	1.059
Proportion of total variance (%)	34.600	26.150	15.550	7.570
Cumulative variance (%)	34.600	60.750	76.300	83.870

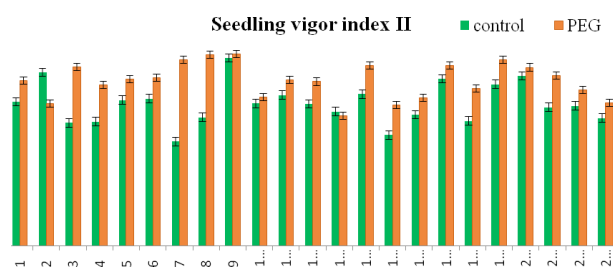


Fig. 3. Mean value of wheat genotypes by using control and PEG 6000 solutions for seedling vigor index I

significant relations among the observed traits (Table 3). Germination per cent (GP) had significant positive correlation with germination rate, shoot length and seedling vigor index I and negative correlation with root dry weight. Germination rate (GR) showed significant positive correlation with shoot length whereas it had significant negative correlation with mean germination time, root length and root dry weight. Among the observed traits, mean germination time had significant negative correlation with seedling vigor index II while the other traits had non-significant correlations. Root length had significant positive correlation with shoot and root dry weights and seedling vigor index I and seedling vigor index II. Shoot length had significant positive correlation with shoot dry weight and seedling vigor index I and significant negative correlation with root dry weight. Shoot dry weight had significantly different positive correlation with seedling vigor index I and seedling vigor index II. Moreover, root dry weight had significantly different positive correlation with seedling vigor index II. Meanwhile, seedling vigor index I had significantly different positive correlation with seedling vigor index II. Correlation analysis explains the connection between two variables, which is valuable in the field of plant sciences as it creates associations that may be used to consider the relationship between many features (Ahmed *et al.*, 2019). Understanding the correlation among these traits was very important to improve the efficiency of breeding for drought tolerance in wheat (Sallam *et al.*, 2019). This experiment studied the correlations among germination percentage, germination rate, mean germination time, root length, shoot length, dry weight of roots and shoots, seedling vigor index I and II under drought stress condi-

tion. Most of the correlations were positively and negatively significant which indicated that these traits tend to move directly and indirectly together and had tendencies to increase or decrease. These tendencies one trait observed to choose another trait together. Germination percentage showed positive and significant relationship with dry weight of root that was similarly found by previous research (Rauf *et al.*, 2007).

The first important four components explained 83.87 % of the total variation under the treatment conditions (Table 4). The first component (PC1) related to 34.60% of the variation, mostly affected by seedling vigor index II, root length and root dry weight with the principal component (PC) scores of 0.418, 0.399 and 0.326. Among the observed traits, the second component (PC2) accounted for 26.15% of the variation; the most effective trait was root dry weight with the (PC) score of 0.333. For 15.55% of total variation, the third component (PC3) was mostly influenced with the variation of germination rate. The fourth component (PC4) was observed with 7.57% of total variance which had high correlations with germination per cent. Principal component analysis is a statistical approach for reducing the dimensionality of huge data sets and enhancing comprehension while minimizing information loss. These results are in agree with those of Kaya, Akcura and Taner (2006) who reported that the selection of genotypes that had high PCA1 and PCA2 are suitable for stress conditions.

CONCLUSION

The results of this study indicated that a progressive osmotic stress induced by PEG-6000 caused significant changes in germination and seedling growth along the tested wheat genotypes. Significant interactions revealed that genotypes variably responded to osmotic stress treatments; hence could be provided the best opportunity to select drought tolerant genotypes at seedling growth stages. Among the observed traits, seedling vigor index II, root length, and root and shoot dry weights showed highly positive correlations and can be used to select for drought-tolerant traits. Furthermore, genotypes such as the seventeen evaluated showed longer root length and higher root dry weight and seedling vigor

index II values, along with larger PCA1 and lower PCA2 scores, indicating trait stability. Therefore, these traits could be effectively used in drought tolerant breeding programs.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the

Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) Ph.D. Research Scholarship for its generous support, which was instrumental in the successful completion of this study.

REFERENCES

- Abro, A.A., S. Memon, S.A. Abro, E.K. Sam, Ru-yu He, M.H. Rind and Z. Solangi 2020. Evaluation of drought tolerance in wheat (*Triticum aestivum* L.) cultivars at early seedling stage using polyethylene glycol induced osmotic stress. *Journal of Animal & Plant Sciences*. 30 (4): 950-957.
- Ahmad, M., Shabbir, G., Minhas, N.M. and Shah, M.K.N. 2013. Identification of drought tolerant wheat genotypes based on seedling traits. *Sarhad J. Agric.* 29(1): 21-27.
- Ahmed, H.G.M.D., Sajjad, M., Li, M., Azmat, M.A., Rizwan, M., Maqsood, R.H and Khan, S.H. 2019. Selection criteria for drought tolerant bread wheat genotypes at seedling stage. *Sustainability*. 11(9): 2584.
- Ashraf, M. and Foolad, M.R. 2005. Presowing seed treatment-A shotgun approach to improve germination, plant growth, and crop yield under saline and nonsaline conditions. *Advances in Agronomy*. 88: 223-271.
- Badiow, F.A., Diouf, D., Sane, D., Diouf, O., Goudioby, V. and Diaalo, N. 2004. Screening cowpea (*Vigna unguiculato* L.) walp. Varieties by inducing water deficit and RAPD analyses. *African Journal of Biotechnology*. 3(3): 174-178.
- Bagher, G., Ghorbani, M. and Ghasemi, M. 2012. Effects of different levels of osmotic potential on germination percentage and germination rate of barley, corn and canole. *Iranian Journal of Plant Physiology*. 2: 413-417.
- Bayoumi, T.Y., Manal H.E. and Metwal, E.M. 2008. Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. *African Journal of Biotechnology*. 7: 2341-2352.
- Dass, A., Kushwaha, H.L., Sahoo, P.K., Dhar, S., Choudhary, A.K., Khura, T.K., Babu, S., Singh, A., Mani, I., Kumar, M., Kumar, R. and Yadav, D. 2023. Comparative analysis of machine-planted and manual-planted wheat on crop and water productivity, and profitability under system of wheat intensification management. *Front. Sustain. Food Syst.* 7: 1187647. doi: 10.3389/fsufs.2023.1187647.
- Dezfuli, P.M., Sharif-Zadeh, F. and Janmohammadi, M. 2008. Influence of priming techniques on seed germination behavior of maize inbred lines (*Zea mays* L.). *ARPJ Journal of Agricultural and Biological Science*. 3(3): 22-25.
- Dhanda, S.S., Sethi, G.S. and Behl, R.K. 2004. Indices of drought tolerance in wheat genotypes at early stages of plant growth. *Journal of Agronomy and Crop Science*. 190(1): 6-12.
- FAO [Food and Agricultural Organization]. 2022. Food and Agricultural Organization of the United Nations, World Food Program, Cereal supply and demand, Rome, Italy.
- International Seed Testing Association. 1999. International rules for seed testing. Rules 1999 (No. Suppl).
- Jajarmi, V. 2009. Effect of water stress on germination indices in seven wheat cultivars. *World Acad. Sci. Eng. Technol.* 49:105-106.
- Kushwaha, H. L., Dass, A., Khura, T. P., Sahoo, P. K., Singh, M. K. and Mani, I. 2018. Design, development and performance evaluation of manual planter for system of wheat intensification. *Indian J. Agric. Sci.* 89: 678-687. doi: 10.56093/ijas.v89i4.88867
- Jisha, K.C., Vijayakumari, K. and Puthur, J.T. 2012. Seed Priming for abiotic stress tolerance: an overview. *Acta Physiol Plant.* 35: 1381-96.
- Kaya, Y., Akçura, M. and Taner, S. 2006. GGE-biplot analysis of multi-environment yield trials in bread wheat. *Turkish Journal of Agriculture and Forestry*. 30(5): 325-337.
- Khakwani, A.A., Denett, M.D. and Munir, M. 2011. Early growth response of six wheat varieties under artificial osmotic stress condition. *Pakistan*

- Journal of Agricultural and Biological Science*. 48:119-123.
- Michel, B.E. and Kaufmann, M.R. 1973. The osmotic potential of polyethylene glycol 6000. *Plant Physiology*. 51(5): 914-916.
- Ming, D.F., Pei, Z.F., Naeem, M.S., Gong, H.J. and Zhan, W.J. 2012. Silicon alleviates PEG induced water-deficit stress in upland rice seedling by enhancing osmotic adjustment. *Journal of Agronomy and Crop Science*. 198: 14-26.
- MOALI [Ministry of Agriculture, Livestock and Irrigation], 2022. Production and sown areas of wheat. Myanmar Agriculture at a Glance, Department of Agricultural Land Management and Statistics, Department of Planning. Ministry of Agriculture, Livestock and Irrigation, Nay Pyi Taw, Myanmar, p.176
- Moucheshi, A., Heidari, B. and Assad, M.T. 2012. Alleviation of drought stress effects on wheat using arbuscularmycorrhizal symbiosis. *International Journal of Agriscience*. 291: 35-47.
- Nezhadahmadi, A., Prodhan, Z.H. and Faruq, G. 2013. Drought tolerance in wheat. *Scientific World Journal*. 11: 610-721. doi: 10.1155/2013 / 610721.
- Ranal, M.A. and Santana, D.G.D. 2006. How and why to measure the germination process?. *Brazilian Journal of Botany*. 29: 1-11.
- Rauf, M., Munir, M., Hassan, M., Ahmad, M. and Afzal, M. 2007. Performance of wheat genotypes under osmotic stress at germination and early seedling growth stage. *African Journal of Biotechnology*. 6(8).
- Raza, S., Saleem, M.F., Khan, I.H., Jamil, M., Ijaz, M. and Khan, M.A. 2012. Evaluating the drought stress tolerance efficiency of wheat (*Triticum aestivum* L.) cultivars. *Russian Journal of Agricultural and Socio-Economic Sciences*. 12(12): 41-46.
- Rehman, S., Harris, P.J.C., Bourne, W.F. and Wilkin, J. 1997. The effect of sodium chloride on germination and the potassium and calcium contents of Acacia seeds. *Seed Science and Technology (Switzerland)*. 25(1): 45-57.
- Saghafikhadem, A. 2012. The effect of drought on growth and yield of wheat. *American Journal of Scientific Research*. 44: 110-115.
- Sallam, A., Alqudah, A.M., Dawood, M.F., Baenziger, P.S. and Börner, A. 2019. Drought stress tolerance in wheat and barley: advances in physiology, breeding and genetics research. *International Journal of Molecular Sciences*. 20(13): 31-37.
- Shereen, A., Khanzada, M.A., Baloch, M.A.W., Asma, B.H., Shirazi, M.U. and Khan, M.A. 2019. Effects of PEG induced water stress on growth and physiological responses of rice genotypes at seedling stage. *Pakistan Journal of Botany*. 51(6): 2013-2021. doi:10.30848/PJB2019-6(13).
- Španiæ, V., Iakovia, M. and Marèek, T. 2017. Wheat germination and seedlings under PEG-induced conditons. *Agronomskiglasnik: Glasilo Hrvatskogagronomskogdruštva*. 79(3): 99-109.
- Swain, P., Anumalla, M., Prusty, S., Marndi, B.C. and Rao, G.J.N. 2014. Characterization of some Indian native land race rice accessions for drought tolerance at seedling stage. *Australian Journal of Crop Science*. 8(3): 324-331.
- Tang, D., Wei, F., Qin, S., Khan, A., Kashif, M.H. and Zhou, R. 2019. Polyethylene glycol induced drought stress strongly influences seed germination, root morphology and cytoplasm of different kenaf genotypes. *Industrial Crops and Products*. 137:180-186. doi:10.1016/j.indcrop. 2019.01.019.
- Xie, X., Zhang, X. and He, Q. 2013. Identification of drought resistance of rapeseed (*Brassica napus* L.) during germination stage under PEG stress. *Journal of Food, Agriculture and Environment*. 11(2): 751-756.